Caterpillar MorElectric™
DOE Idle Reduction Demonstration Program

Final Report

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DISCLAIMER

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Background:

This project titled "Demonstration of the New MorElectric^{TM} Technology as an Idle Reduction Solution" is one of four demonstration projects awarded by the US Department of Energy in 2002. The goal of these demonstration and evaluation projects was to gather objective in-use information on the performance of available idle reduction technologies by characterizing the cost; fuel, maintenance, and engine life savings; payback; and user impressions of various systems and techniques.

In brief, the Caterpillar Inc. project involved applying electrically driven accessories for cab comfort during engine-off stops and for reducing fuel consumption during on-highway operation. Caterpillar had equipped and operated five new trucks with the technology in conjunction with International Truck and Engine Corporation and COX Transfer.

The most significant result of the project was a demonstrated average idle reduction of 13.8% for the 5 truck MEI fleet over the control fleet. It should be noted that the control fleet trucks were also equipped with an idle reduction device that would start and stop the main engine automatically in order to maintain cab temperature. The control fleet idle usage would have been reduced by 3858 hours over the 2 year period with the MEI system installed, or approximately 2315 gallons of fuel less. (calculations assume a fuel consumption of 0.6 gallons per hour for the 13 liter engine at idle) The fuel saved will be significantly larger for higher displacement engines without idle reduction equipment such as the engine auto start/stop device used by COX Transfer. It is common for engines to consume 1.0 gallons per hour which would increase the fuel savings to approximately 1260 gallons per truck per year of typical idling. (1800 hours idle/yr)

MorElectric^{TM} System Description:

The MorElectric^{TM} system is composed primarily of three major components; the high voltage belt driven generator, the auxiliary power unit (APU), and the integrated HVAC unit with high voltage electric air-conditioning compressor. In addition to these major components, the system also includes a high voltage electric heater, a shore power(allows system to use 240vac utility power instead of the APU) interface module, and a 3 kW electronic battery charger.

Figure 1 is a depiction of the major system components, while figure 2 shows the components as applied to the truck.

Figure 1: Primary MEI Components

Figure 2: MEI System in Truck Application

Usage:

During the period from November 2004 through December 2006, Cox Transfer operated the five MorElectric™ system-equipped International 9200i class 8 trucks. As part of the test, five additional non-MEI trucks (which were built at the same time and to the same specifications as the MEI fleet) operated as a control group for the field test demonstration. The MEI equipped fleet of trucks accumulated a total of 877,920 miles, while the control fleet accumulated a total of 1,044,374 miles. The difference in totals is due primarily to the time required to retrofit the trucks with the MEI system.   Figure 3 is a graphical depiction of the mileage accumulation over time of both fleets. It can be seen that once operating, the MEI fleet accumulated miles at the same rate as the control fleet which attests to the "up-time" of the MEI system.

Figure 4 is a summary of key data for the MEI equipped fleet. System mileage, main engine hours, fuel used, overall percent idle, and APU engine hours are listed for each truck. The difference in overall miles per truck is due to the staged installation of the MEI system. Of particular interest is the average percent idle time for the group of 5 MEI equipped trucks which is 13%, or roughly half of the control fleet average of 26.8%.

Figure 5 is a summary of the same data (with the exception of the APU) for the control truck fleet of 5 trucks. The control fleet finished the program with slightly more miles overall since the trucks were not removed from service to perform the MEI system installation. It is noteworthy to point out the large variation in percent idle time for both the MEI and control fleet. Future demonstration programs would benefit from a larger set of field test vehicles to avoid variation in driver behavior.

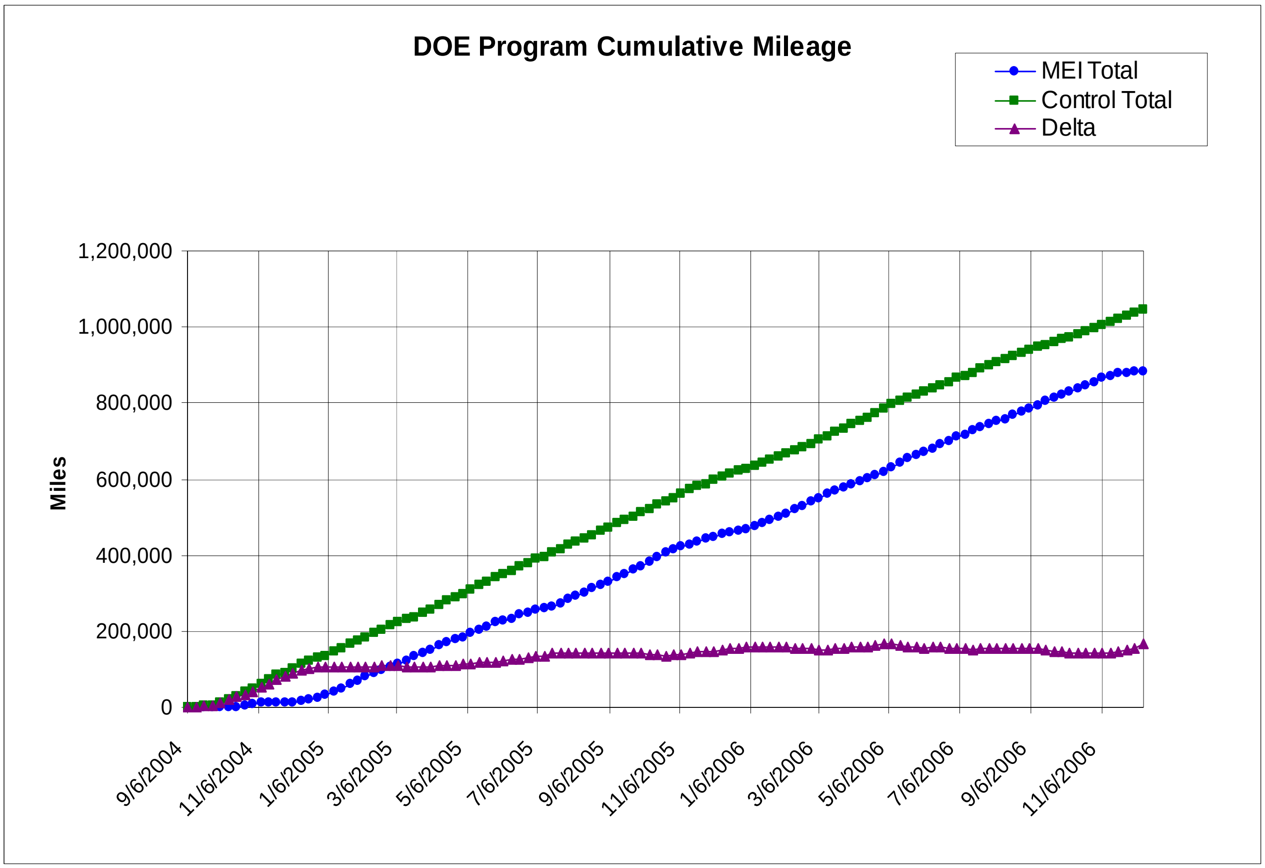

Figure 3: MEI & Control Truck Mileage Accumulation

Cox Truck #	System Mileage (miles)	Main Engine Hours	Fuel Used (gallons)	% Idle Time	APU Engine Hours
450	232,946	4,558	35,202	10.9%	1,859
451	141,531	3,459	22,197	18.7%	2,036
452	191,456	4,484	27,644	12.0%	2,865
453	183,805	3,725	30,067	10.2%	2,450
454	128,182	3,152	19,841	14.3%	1,154
Total	**877,920**	**19,378**	**134,950**	**13.0%**	**10,364**

Figure 4 - Overall Usage – MEI Fleet

Cox Truck #	Mileage (miles)	Main Engine Hours	Fuel Used (gallons)	% Idle Time
455	209,527	5,809	34,690	29.4%
456	208,399	5,079	31,877	19.0%
457	225,221	6,323	33,408	27.5%
458	189,533	5,656	30,939	36.2%
459	211,694	5,089	33,855	20.5%
Total	**1,044,374**	**27,955**	**164,769**	**26.8%**

Figure 5 - Overall Usage – Control Fleet

Fuel Consumption:

Fuel mileage for the trucks has been calculated in two different ways. The moving fuel mileage is calculated by using only the fuel consumed when the trucks are moving (idle and idle reduction data are excluded). This data was collected to verify any fuel saving due to the more efficient MEI components. In the second method, the overall “tank” fuel mileage includes all fuel use whether thru the truck moving, idling with the main engine, or utilizing the APU. This method accounts for fuel savings due to reduced idling as well as more efficient MEI components.

The fuel usage of the main engine is downloaded thru Cox Transfer’s PeopleNet tracking software. Figure 6 shows a sample data output from PeopleNet.

Performance report for vehicle 451 (ACTCL)

ITEM	MEASURE	% / AVG
REPORT SCOPE		
Earliest reading	09/30/2005 18:00	n/a
Latest reading	10/31/2005 18:00	n/a
Report duration	744.00 hours	n/a
DISTANCE/FUEL		
Odometer	46366.3 to 55644.4	n/a
Total Distance	9,278.1 miles	avg 299.3 / day
Total Fuel	1,440.250 gallons	n/a
Average MPG	6.44 miles/gallon	n/a
Average Speed	50.3 mph	n/a
TIME BREAKOUT		
Engine Time	222.17 hours	29.9%
Moving Time	184.41 hours	24.8%
Over RPM Time	113.58 minutes	0.9%
Over Speed Time	0.46 hours	0.2%
Excess Speed Time	0.00 hours	0.0%
IDLE BREAKOUT		
Long Idle Time	16.97 hours	7.6%
Long Idle Count	102	avg 9.98 mins each
Long Idle Fuel	6.500 gallons	avg 0.06 gals each
Short Idle Time	20.80 hours	9.4%
Short Idle Count	2747	avg 27 seconds each
Short Idle Fuel	9.625 gallons	avg 0.00 gals each
PTO BREAKOUT		
PTO Fuel	0.000 gallons	n/a
PTO Time	0.00 hours	n/a

Fuel mileage including idle, but not APU

Idle time >5 minutes

Idle time <5 minutes

Figure 6: Sample PeopleNet data

Moving fuel usage is calculated by subtracting the idle fuel usage specified in the PeopleNet report from the overall fuel usage. Moving fuel mileage is then calculated by dividing the miles driven by the moving fuel usage. Figure 7 shows a plot of the moving fuel mileage for both the MEI and control trucks. When the data is fitted with 6th order polynomials, there appears to be a 0.2 to 0.3 MPG increase with the MEI truck fleet.

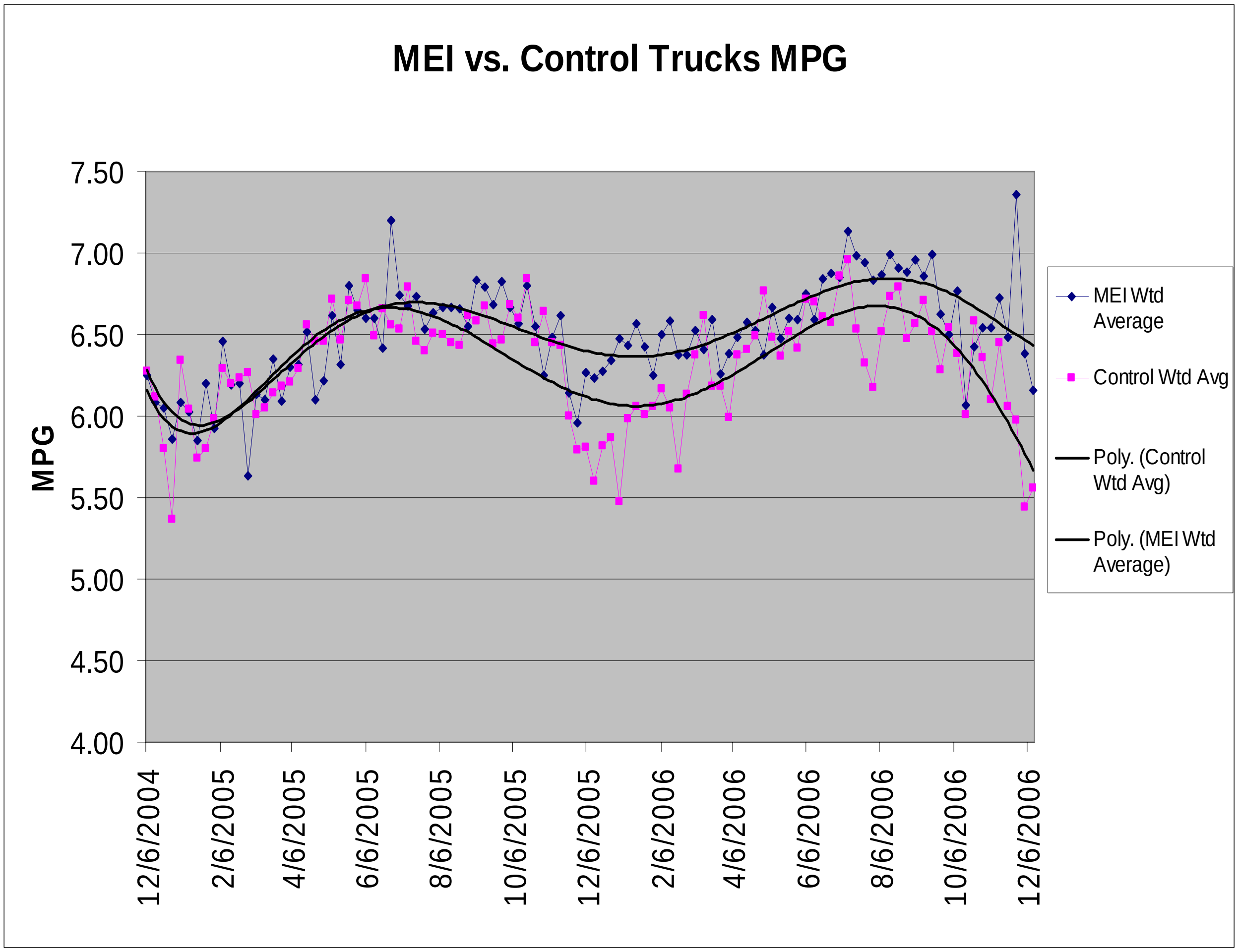

Figure 7: MEI & Control truck moving fuel mileage

The data from PeopleNet does not include the fuel used by the APU during operation, only the main engine. In order to calculate the "tank" fuel mileage, miles driven was divided by fuel used as recorded on actual fuel receipts. Figure 8 is the running cumulative "tank" mileage calculated by dividing the overall miles driven by the overall fuel usage starting in January 2006. This chart shows a 0.17 MPG advantage of the MEI fleet over the control truck fleet for the most recent data. Note that figure 8 is a cumulative mileage chart vs. the chart shown in figure 7. The cumulative chart tends to improve the accuracy of the data over time, whereas the chart in figure 7 indicates "seasonal" variation in the mileage data.

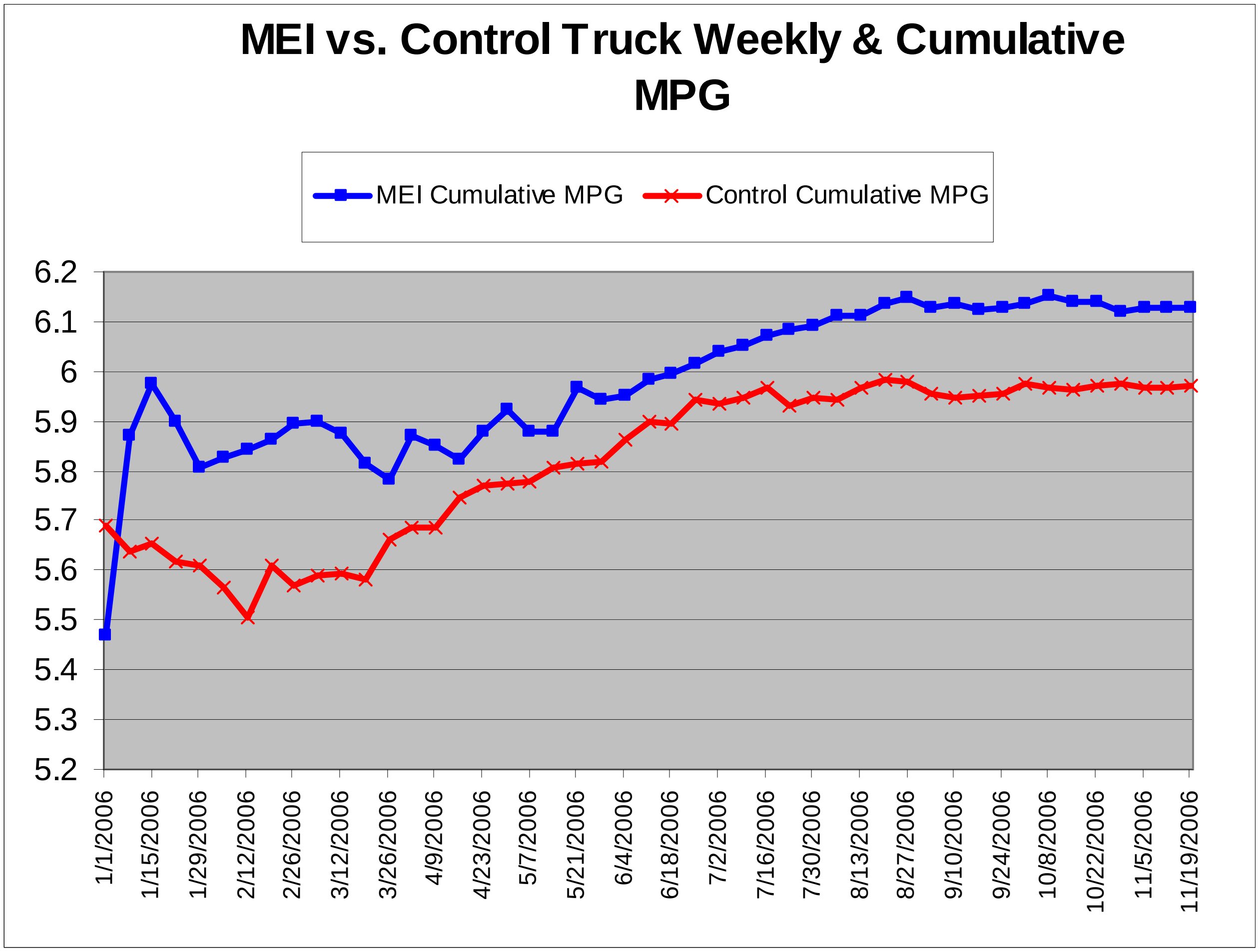

Figure 8: "Tank" fuel mileage

Another interesting correlation is the plot of average ambient temperature in Peoria vs. the moving mileage of both the MEI and control fleets. This is shown as figure 9. It can be seen that there is a trend of lower mileage during the colder months of winter for both fleets. This is likely the result of extended idling for the purpose of cab heating. There is a clear mileage advantage during the winter of 2005/2006 for the MEI truck fleet. (see figure 9)

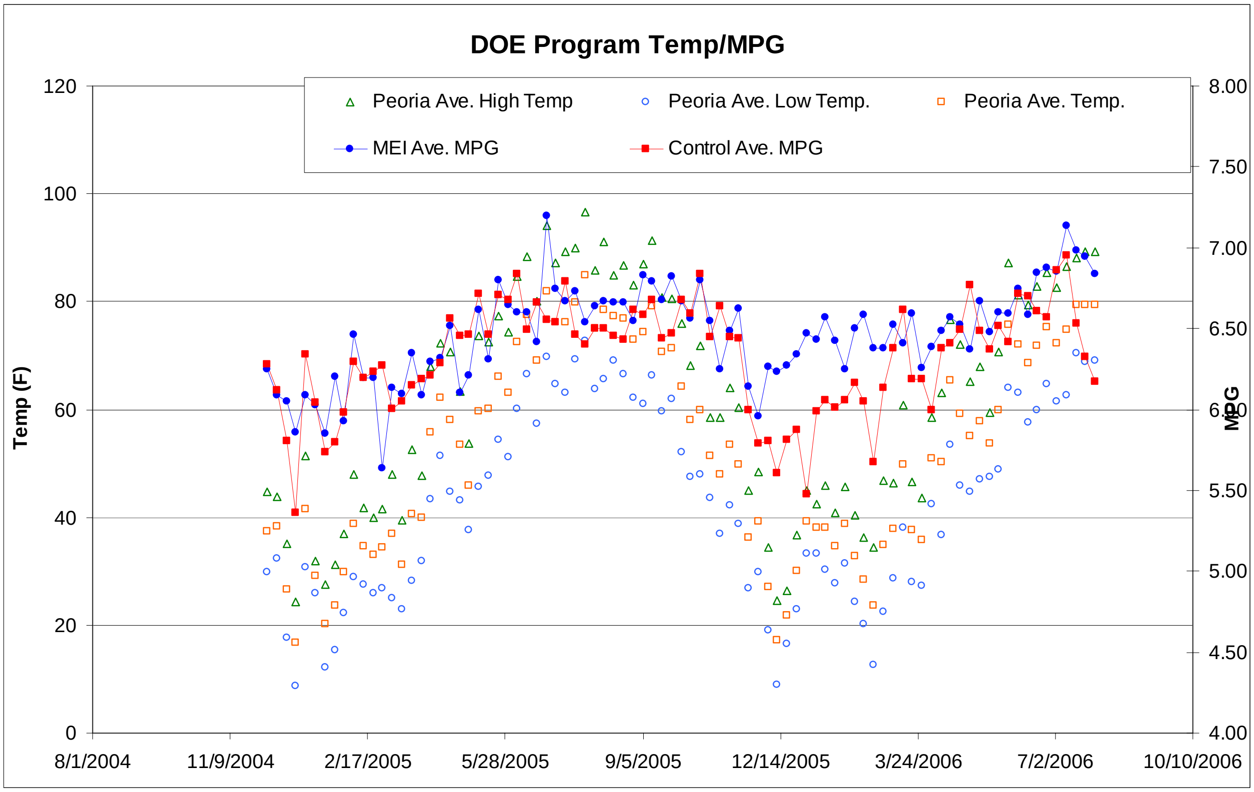

Figure 9: Moving Mileage vs. Ambient Temperature

System Issues:

Throughout the field test, all issues were categorized and recorded in a computer database. Figure 8 is a bar chart of quantity verses category of issue. The top two issues involved high voltage harnesses and Power Electronics Module(PEM) software. The PEM software issues were largely solved early in the field test, but the harness/connector issues developed over time due to salt spray exposure. Note that the last two bars indicate non-MEI issues as well as preventative maintenance/informational issues.

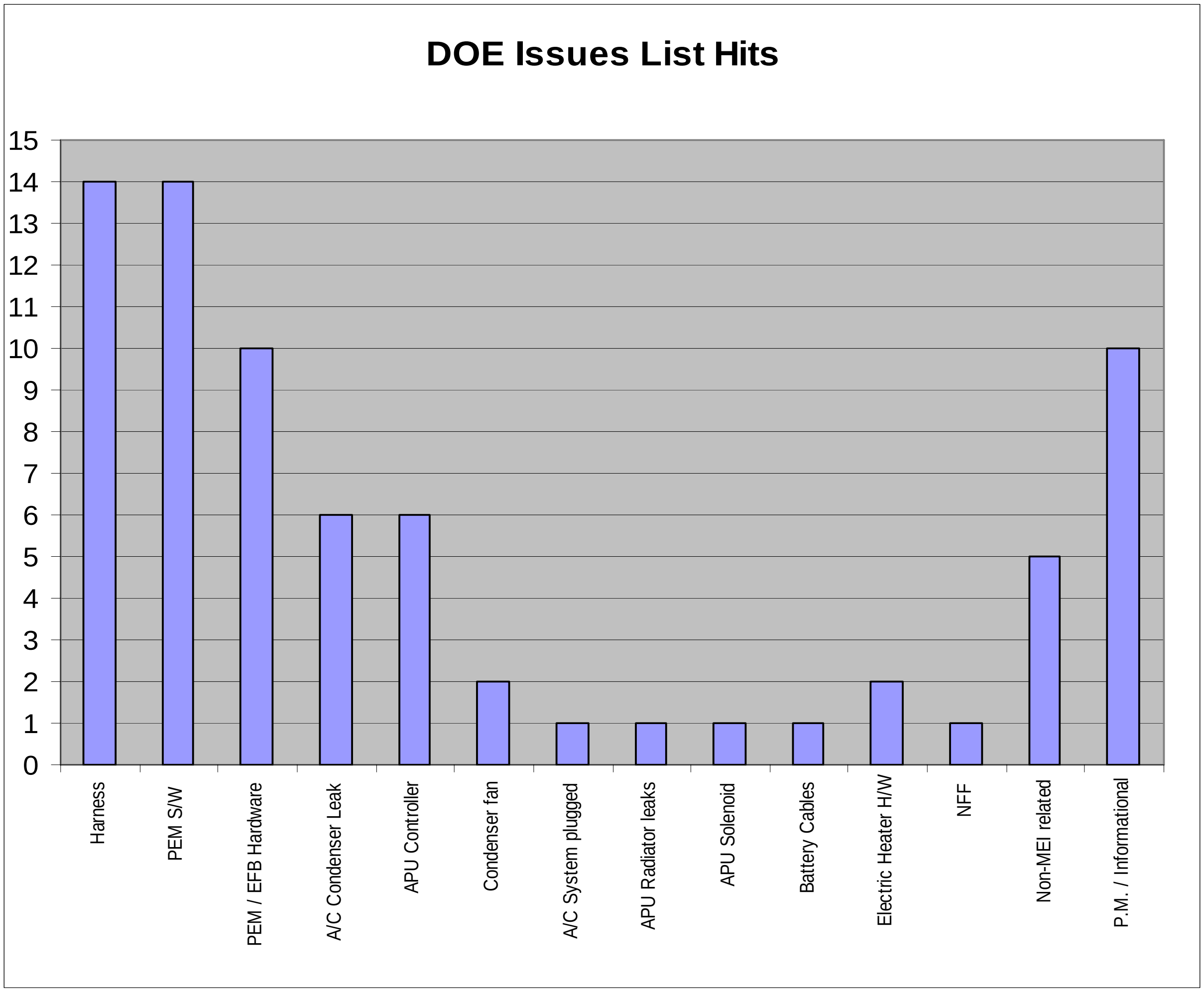

Figure 8: System Issues

The other top areas included PEM hardware, air-conditioning condenser leaks, and the electronic APU controller module. Root causes were found for all problems as well as solutions to correct the problems. As an example, a potting material with better tolerance to thermo-cycling and salt spray was identified as the solution for the harness/connector category of issues. PEM software and hardware issues were addressed by improved designs. The condenser leaks were addressed by changing from a thin wall to a “tube and fin” design.

Feedback – Shop Foreman Summary:

The following is a summary of the COX Transfer shop foreman feedback (note- the data is un-edited):

System Performance

1. They(drivers) recognize there were a lot of issues, some still to be resolved.

2. Too many connector failures throughout the program.
3. A lot of nuisance issues early in the program.
4. System working good at end of program.
5. Drivers wanted better temperature control.
6. The CB noise was more of an issue than Cat perceived it to be.
7. ~80% of the issues were addressed / resolved in a timely manner.
8. ~20% of the issues took too long.
9. Should have installed a disconnect switch instead of asking the driver to remove B+ at the PEM(power electronics module).
10. Alan(shop foreman) was very surprised they did not experience a generator failure.
11. Cox not being able to connect with ET(Cat dealer electronic service tool) was an inconvenience.
12. Not sure they realized the economy savings they were expecting.

Drivers Likes/ Dislikes

1. Liked the system, when it worked.
2. Liked that the APU ran constant.
3. They thought the system should have had more bugs worked out before introducing it to them.
4. They lost $ when their truck would go down.

Management Likes/Dislikes

1. MEI Hotline did not work as explained. They never helped resolve, only helped put driver up in hotel and passed failure information on to engineering to fix the problem.
2. They think the drivers may have used APU even when not needed.
3. A couple times, they felt like no one was concerned about their truck's being down.
4. No one really appreciates the time it took to move from down truck.
5. Mark thought they would have the system on their trucks until the trucks were traded.

Program Issues

1. They didn't realize there were so many different companies involved.
2. A lot of the initial Cat people were no longer on the program. This lost some gentleman’s agreements.
3. Did not receive some payments in a timely manner.

General Comments

1. Start/stop feature on APU would have been nice.
2. Temperature/battery sensing would have been nice.
3. This system probably would not make sense for their type of routes.
4. Mixed feelings on integrated system, might like to be able to re-use.

Driver Feedback:

The next section contains comments from the drivers of the MEI equipped trucks. The following questions were asked of each driver:

1. What do you like about the MorElectric System?
2. What do you dislike?…. or suggestions for improvements?

3. Does the MorElectric provide adequate heating and cooling?
4. Have any of the components had any problems during the month?
    a. APU
    b. Shore Power
    c. HVAC
    d. Generator
5. Any comments from other drivers concerning the MorElectric system on your truck?
6. How would you rate the Overall operation of the MorElectric System during the month?

Everett Welty
Unit #451 requested to be moved after numerous failures at initial project start

1. System needed more testing before installation on a class 8 truck. This may have caught small problems before they became major problems.

2. Heat was too hot, not enough plus or minus control, unit was oversized for what is required to cool or heat
3. Too much heat, just right to too much on cooling
4. APU – PEM problems
5. None- just the normal look and see but no real questions
6. Good to Fair when operational

Dick Brandon
Unit #450

1. Worked good when it worked, liked the constant running of the small engine on the generator, giving white noise
2. The down time was very critical to my pay check, I needed to sleep but had to transfer my needed supplies to another power unit then try to make my deliveries on time. Connectors needed to be improved and should have all been replaced after the first failure I had.
3. Just right after control was reworked
4. Heater element malfunctioned at the end of the project and a bad connector made the air system not work during the project
5. System was great when it worked
6. Fair during the life of the program
   (shop foreman comment) - Wishes he still had the system on the truck and all the bugs worked out.

Dan Hert
Unit #452

1. Liked not having to run main engine to keep batteries charged up. Liked that during the cold weather starting the generator engine heated the main engine making it start quicker and easier.
2. The system needed to have a better heat distribution through out the cab, when running the heat system it seemed that from the floor to 1 foot above the floor was very cold and

never seemed to warm up. Condensation on the inside of the windows was a real pain and this was experienced on both the cooling and heat cycles. Need to improve the way to check the oil and add oil to the generator engine.

3. Too much cooling and too much heat.
4. APU controller failure, PEM problems, shore power was awaste and never used, HVAC heater element went bad. Boy I never realized I had all these failures till you asked me.
5. Few concerned drivers, more curious than interested in how the system worked.
6. Good at the end. System had a lot of the bug worked out of it and would give the system a thumbs up, I'm missing the white noise generated by the small engine

Clyde Widmer

Unit #454

1. liked not hsaving to run the main engine to keep cab hot or cold
2. noise the system put in my C/B radio and AM radio was just terrible
3. Just the right amount of heating and cooling
4. Had problems with APU, heater air and the generator controller. Never had problems with the shore power but I never used it either
5. No one ever asked me anything about the system
6. Good to fair while I ran this unit

Project Summary:

This project was a successful in-use demonstration of an idle reduction technology designed by Caterpillar Inc. and is unique in the designs' deep integration into the truck chassis. Benefits demonstrated by the MEI system include a 13.8 % idle reduction, improved driver comfort during rest periods, quicker engine starts in cold weather, higher output 12 volt d.c. charging system, and less costly "jump starts"(the APU can be "jump started" from a standard automobile which in turn provides enough power to start the main engine) just to name a few.

The effects on maintenance and engine life were not determined due to the relatively short duration of the demonstration (2 years), small sample size (5 units), and the negative effects of technical issues associated with the new technology introduction. Issues with the control of the sensor-less switched reluctance generator, and environmental effects on high voltage d.c. connectors were the major contributors to system down time.

Over the course of the demonstration, much was learned regarding idle reduction technology. The following is a list of several "lessons learned":

- OEM's are very reluctant to integrate new/unproven technology into their truck chassis's. This is a requirement for highly integrated idle reduction systems in order to make the systems feasible.

- Electronic power component placement is extremely important due to environmental effects such as salt-spray and heat on high voltage connectors.
- Operators will quickly adapt to idle reduction systems even after years of engine idling habits have been formed.
- One unanticipated benefit was the “low steady drone” created by the APU running which masked other random noise and improved operator sleep.
- Once drivers became accustomed to using the APU rather than running the main engine, they had a tendency to run the APU a high percentage of the time that the truck was not being driven. (in situations where the main engine would not have been started - in trucks without idle reduction equipment - such as on moderate weather days)   This was another unexpected factor which impacted the fuel savings negatively.
- Shore power modules and electrical cables were installed on all 5 of the demonstration trucks, but were never used do to lack of utility service. Drivers have also indicated a preference to sleeping overnight in locations in close proximity to the next delivery such as a near-by parking lot, or in factory lots. This is a fundamental problem with the idea of utilizing shore power to avoid engine idling. (lack of available electrical connections needed to satisfy the needs of idle reduction systems)
- The economics of idle reduction systems alone is not enough to create a market for high quality integrated idle reduction systems. Until this technology becomes mature, legislation will be needed for wide-spread use to be achieved. Incentives may be required to help move forward the use of these systems until they become mandatory on new trucks.

With the program end in December of 2006, the MEI components were removed from the 5 truck MEI fleet. The trucks were restored to their original condition and placed back into service with COX Transfer of Eureka, IL. Lessons learned as well as system and component knowledge obtained from this program may very well be carried forward into future Caterpillar Inc. products.

Overall, the project can be considered a success with nearly 2 years and 877,000 miles of experience with the idle-reduction system operating. The drivers that were selected for the program adapted quickly to the new technology and preferred it to engine idling once initial technical issues had been overcome.

John Bernardi
Cat Electronics
DOE Idle Reduction Demonstration Project Lead